The invention describes a method of manufacturing an OLED device (10), which method comprises applying a number of conductive strips (4) onto a substrate (1); forming a series of openings (40) in at least one conductive strip (4) along a sealing path (5) to expose the substrate (1) in those openings (40); applying a line of sealant (50, 51) along the sealing path (5) to enclose an organic layer (2) bounded by the conductive strips (4); and placing a cover lid (3) onto the sealant (50, 51) to encapsulate the OLED device (10). The invention also describes an OLED device (10), comprising a number of conductive strips (4) applied onto a substrate (1), wherein at least one conductive strip (4) comprises a series of openings (40) exposing the substrate (1) along a sealing path (50); an organic layer (2) deposited on the substrate (1) within a region bounded by the conductive strips (4); a cover (3) for sealing the OLED device (10); and a line of sealant (50, 51) applied along the sealing path (5), which sealant (50, 51) adheres at least to the cover lid (3) and to the substrate (1) exposed in the openings (40) of a conductive strip (4).
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OLED DEVICE AND METHOD OF MANUFACTURING THE SAME

FIELD OF THE INVENTION

The invention describes a method of manufacturing an OLED device. The invention further describes an OLED device.

BACKGROUND OF THE INVENTION

Organic light-emitting diode (OLED) devices used in applications such as lighting generally comprises a relatively large organic light-emitting area deposited onto a transparent substrate. Contact pads for the anode and cathode are arranged along the outside of the organic layers and are used to supply an electric current across the organic layer when they are connected to a power supply. A relatively large contact pad area ensures a homogenous current flow through the organic layer and a correspondingly homogenous light output. An OLED device must be reliably sealed in order to protect the organic light-emitting layer, which can otherwise become damaged if moisture penetrates the seal. Prior art OLED devices are usually encapsulated by applying a line or ring of adhesive on the contact pads all the way around the organic layer, and a cover lid is then pressed onto the sealant, which may be hardened in a subsequent curing step.

The OLED is then mounted securely into an appliance, for example a frame or housing. Since the contact pads are made as long as possible, they usually extend almost all the way along the edges of the substrate. For example, an anode can extend along one side of the substrate for almost all of its length, while the cathode extends along the other three sides of the substrate, or vice versa, depending for example on whether the device is a bottom-emitting or a top-emitting OLED. A gap between the anode and cathode is necessary since these must be electrically isolated from each other, and this gap - usually at a corner of the substrate - is kept quite small. In the gap between the anode and cathode (which must be spatially separate on the substrate), the sealant - usually an adhesive - can provide a reliable bond between the cover lid and the substrate. During operation of the OLED device, the interface between the OLED and the cover lid is subject to mechanical forces due, for example, to shock, pressure exerted
by the housing, handling, or thermal expansion/contraction. These forces can cause the rigid sealant to part from the surface of a contact pad, leaving a gap through which moisture can creep into the organic layer, thus irreparably damaging the OLED device.

It is therefore an object of the invention to provide an improved way of encapsulating an OLED device to avoid the problems described above.

SUMMARY OF THE INVENTION

This object is achieved by the method according to claim 1 of manufacturing an OLED device, and by the OLED device of claim 9.

According to the invention, the method of manufacturing an OLED device comprises the steps of applying a number of conductive strips onto a substrate; forming a series of openings in at least one conductive strip along a sealing path to expose the substrate in those openings; applying a line of sealant along the sealing path to enclose an organic layer bounded by the conductive strips; and placing a cover lid onto the sealant to encapsulate the OLED device. Here, the 'sealing path' is to be understood to be a virtual line running all the way around the organic layer along the openings in the conductive lines, whereby the sealing path can traverse the openings or run alongside the openings, or can run between the openings, as will be explained below to give a solder seam. The 'substrate' is to be understood to be a layer onto which the conductive strips are applied or deposited in the manufacturing process. For a bottom-emitting OLED, for example, the substrate can be a clear glass layer, but the substrate could also be a glass carrier onto which a layer has been applied, for example a barrier layer (e.g. silicon dioxide), a transparent conducting oxide, etc.

An obvious advantage of the method according to the invention is that the sealant can make a robust bond between the cover lid and the substrate essentially all the way along a conductive strip, since the openings in the conductive strip allow the sealant to contact the substrate exposed in those openings. Since the bonds between sealant and cover lid and between sealant and substrate are able to withstand shear forces, this method provides a very simple way of manufacturing an OELD device which can
withstand a warping or bending of the OLED device caused by external forces during operation of the OLED device.

The method according to the invention provides a reliable adhesion all the way along the sealing path on a conductive strip, unlike a prior art encapsulation, which can only provide a good bond in the relatively small space between neighbouring conductive strips, and for which the bond is unsatisfactory along the conductive strips.

According to the invention, the OLED device comprises a number of conductive strips applied onto a substrate, wherein at least one conductive strip comprises a series of openings exposing the substrate along a sealing path; an organic layer deposited on the substrate within a region bounded by the conductive strips; a cover for sealing the OLED device; and a sealing line applied along the sealing path to adhere at least to the cover lid and to the substrate exposed in the openings of a conductive strip.

The dependent claims and the subsequent description disclose particularly advantageous embodiments and features of the invention. Features of the various embodiments can be combined to arrive at further embodiments.

The conductive strips referred to in the context of the invention may generally be the anode and cathode contact pads, which are usually applied in relatively wide bands around the perimeter of the OLED device and are connected to the positive and negative poles of a power supply. Therefore, in the following but without restricting the invention in any way, the terms 'conductive strips' and 'contact pads' may be used interchangeably.

Prior art manufacturing methods for OLEDs usually involve a number of photolithography steps for applying the various metal layers required for the electrical connections of the device such as the contact pads and any shunt lines that may be required for optimising the current distribution through the device. However, photolithography is very complex and expensive, requiring many steps such as spin-coating, baking, etching etc., as well as requiring clean-room conditions. For this reason, more cost-effective approaches are preferred. Therefore, in a preferred embodiment of the invention, the step of applying a conductive strip comprises printing conductive ink or paste such as a silver nano-ink onto the substrate. This provides a cost-efficient way
of applying metal contact pads (anode and cathode) to the substrate in the desired shapes for current distribution. These printed strips can then be annealed to improve their conductivity. Silver inks are very suitable for such printing techniques on account of their favourable thermal properties and relatively high conductivity. Anode and cathode contact pads printed using such an ink can have a very favourable thickness of only 0.5 \( \mu \text{m} \) to 20 \( \mu \text{m} \), comparable to metal lines formed using a photolithographic process.

The series of openings in a conductive strip can be formed in any suitable manner, using any suitable technique. In one preferred embodiment of the invention, a series of openings is formed in a conductive strip by avoiding a region of the substrate during application of the conductive strip. For example, in a photolithography technique, a photo-resist can be applied in the desired pattern, with no photo-resist being applied to the regions that correspond to the openings in the conductive line. In an etching process, the substrate is exposed in these regions. Using the preferred and simpler printing technique, the openings in a conductive strip are formed in a single step by simply not printing any ink onto these areas.

In another preferred embodiment of the invention, an opening in the conductive strip is formed by performing a laser ablation step to expose a region of the substrate within the conductive strip. Such a laser ablation step can be performed on a conductive strip that has been previously applied to the substrate in any manner, for example using photolithography or ink printing.

The openings can be arranged in any suitable pattern, and can have any suitable shape. In a preferred embodiment of the invention, the openings in a conductive strip are arranged so that the series of openings lies along the sealing path such that a long axis of each opening essentially coincides with the sealing path. For example, the openings can be rectangular in shape and can be arranged so that a series of such rectangular openings lies along the sealing path such that the long axis of each opening essentially coincides with the sealing path. The sealant is then applied directly along the sealing path to lie along the openings. Another arrangement might comprise rectangular openings arranged at an angle to the sealing path. Equally, the openings could be circular or elliptical in shape. Also, the openings could be arranged in a staggered or zig-zag manner about the sealing path, so that the sealing path runs between the openings.
an arrangement can be used in conjunction with an adhesive that spreads during the encapsulation step. A staggered arrangement of openings may be favourable from the point of view of the conductivity of the contact pads. Furthermore, the number of openings in a conductive line, the distance between openings, and the shape, size and orientation of the openings are preferably chosen according to the forces - known or estimated - to which the OLED device may be subject during operation.

Once the conductive lines have been applied with the series of openings to expose the substrate, and an organic layer has been deposited in the region bounded by the conductive lines, the encapsulation step can be performed. In a preferred embodiment of the invention, the step of applying a sealant comprises applying a line of adhesive onto the conductive strip along the sealing path. In this way, the adhesive is applied all the way around the organic layer, and runs along the openings in the contact pads and over the gap between adjacent contact pads. The adhesive can be any suitable adhesive such as epoxy, acrylic, polymer, etc. which can harden on exposure to ultraviolet light or thermal radiation. The adhesive line can be applied using any suitably precise process such as silkscreen printing, plotting using a needle valve, etc.

The adhesive may be quite viscous initially, so that it does not flow into the openings to fill them and wet the substrate. In preferred embodiment of the invention, therefore, the step of encapsulating the OLED device comprises a step of applying pressure to the sealing line to press the adhesive onto the substrate exposed in the openings of a conductive strip so that the adhesive is forced to wet the substrate. An initial adhesive line with a height of about several hundred micrometers can thus be compressed to spread out and to satisfactorily fill the holes given by the openings in the conductive lines, so that the final height of the adhesive line is only about 20 µm. The encapsulation step may also comprise an annealing step to cure the sealant, if necessary.

In another preferred embodiment of the invention, the step of applying a sealing line comprises applying a line of glass solder or 'glass frit' onto the conductive strip along the sealing path.

Preferably, the step of encapsulating the OLED device comprises a laser-assisted glass frit bonding step to melt the glass solder such that the glass solder flows into the openings and coats the exposed substrate. A glass solder can have a favourably
low melting point in the region of 200°C - 400°C, and apart from making a very favourable glass-to-glass bond (substrate to cover lid through the openings in the conductive strip), can also make a very favourably robust glass-to-metal bond (cover lid to conductive strip).

The width of a conductive strip is usually directly related to the size of the OLED. In a preferred embodiment of the invention, the OLED device comprises a plurality of conductive strips, wherein the width of a conductive strip is in the range of 0.1 mm to 10 mm, and an opening in the conductive strip preferably exposes an area of substrate of at least 0.2 mm². The exposed area of the substrate is preferably at least 10%, more preferably at least 50%, most preferably at least 70% of the area of a conductive strip, so that a sealant filling these openings can ensure a robust adhesive bond between the cover lid and the substrate. Furthermore, a solder seam made by melting the glass frit paste as described above gives a hermetic seal, so that the inclusion of a getter between the cover lid and the organic layer is not necessary. Therefore, in a particularly preferred embodiment of the invention, the cover lid comprises a flat glass plate without any recess.

Other objects and features of the present invention will become apparent from the following detailed descriptions considered in conjunction with the accompanying drawings. It is to be understood, however, that the drawings are designed solely for the purposes of illustration and not as a definition of the limits of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a plan view of a prior art OLED device;

Fig. 2 shows a cross-section of the prior art OLED device of Fig. 1;

Fig. 3 shows a plan view of a substrate and contact pads formed using the method according to the invention;

Fig. 4 shows a cross-section section A-A' through an OLED device according to the invention;

Fig. 5 shows a plan view of an OLED device according to the invention.
In the diagrams, like numbers refer to like objects throughout. Elements of the diagrams are not necessarily drawn to scale, particularly the OLED device layer thicknesses and the thicknesses of the contact pads and isolating layers.

5 DETAILED DESCRIPTION OF THE EMBODIMENTS

Fig. 1 shows a plan view of a prior art OLED device 8. Contact pads 42 for an anode and cathode are applied - for example as printed metal lines - around the perimeter of a substrate 1. The anode and cathode contact pads can cover the same area, or one of the contact pads can cover more area than the other, as shown here, depending on the realisation of the OLED. A line of sealant 52 is used to attach a cover lid 31 to protect an organic layer 2 from any moisture. Usually, a prior art OLED device 8 has a recessed cover lid 31, and a getter layer is placed in the recess before encapsulation. The getter acts to absorb any stray moisture in order to protect the organic layer 2. The line of sealant 52 runs along the contact pads 42, so that the contact pads 42 are partly within the bounds of the sealant 52 and partly outside. The positive and negative poles of a power supply 7 are connected to the anode and cathode contact pads 42 during operation of the OLED device 8, which may be part of a luminary or lighting device.

Fig. 2 shows a very simplified cross-section of an outer region of the prior art OLED device 8 of Fig. 1. The diagram shows a contact pad 42 applied to the substrate 1, and an organic layer 2 enclosed by a line of sealant 52 and a cover lid 31. As indicated above, the cover lid 31 is recessed and carries a getter layer 32 (usually, the cover lid with the getter layer 32 would be in direct contact with the organic layer 2). During operation, any structure holding or enclosing the OLED 8 may heat up, causing the substrate 1 or the cover lid 31 to bend slightly, so that shear forces act on the sealant 52. These forces may cause the sealant 52 to detach from the contact pad 42, leaving a break or gap 9 in the seal. Through this gap, moisture can enter the device 8 and cause the organic layer 2 to decompose.

Fig. 3 shows a plan view of a substrate 1 and contact pads 4 formed using the method according to the invention. Here, each contact pad 4 exhibits a series of openings 40 along a sealing path 5. In a later step, a sealant will be applied along this path 5. The substrate 1 is exposed in each opening 40, and the openings 40 can have
been formed by printing the contact pads 4 to leave these areas 40 unprinted, or by performing laser ablation to remove material from the contact pads 4 to expose these areas 40. An organic layer can be deposited in the area bounded by the contact pads 4. A sealant such as an adhesive or a glass solder is then applied along the sealing path 5, and a cover lid is placed onto the sealant. If an adhesive is used, pressure can be applied to the cover lid to press an adhesive into the openings. If a laser assisted glass frit bonding step is carried out, the molten glass frit flows into the openings 40 to make contact with the substrate 1. The robust seal is shown in the section A-A' through the lower contact pad 4 in Fig. 4. Here, the sealant 51, 52 - which may be a cured adhesive 51 or a solidified glass solder 52 - has filled the openings 40 in the contact pad 4.

Fig. 5 shows an OLED device 10 according to the invention, with a sealing line 51, 52 attaching the cover lid 3 to the substrate 1 through the openings 40 in the contact pads 4. In this way, a hermetic seal is obtained between the cover lid 3 and the substrate 1, so that the cover lid 3 can be a simple flat glass lid without any recess or getter layer. This seal, which firmly attaches the cover lid 3 to the substrate 1, is much more robust and can easily withstand the shear forces which can arise during operation of the OLED device 10, so that the OLED device 10 according to the invention has a longer lifetime than a prior art OLED device.

While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art from a study of the drawings, the disclosure, and the appended claims. For the sake of clarity, it is to be understood that the use of "a" or "an" throughout this application does not exclude a plurality, and "comprising" does not exclude other steps or elements. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.
CLAIMS:

1. A method of manufacturing an OLED device (10), which method comprises
   - applying a number of conductive strips (4) onto a substrate (1);
   - forming a series of openings (40) in at least one conductive strip (4)
     along a sealing path (5) to expose the substrate (1) in those openings (40);
   - applying a line of sealant (50, 51) along the sealing path (5) to enclose
     an organic layer (2) bounded by the conductive strips (4);
   - placing a cover lid (3) onto the sealant (50, 51) to encapsulate the OLED device (10).

2. A method according to claim 1, wherein the step of applying a conductive strip (4) comprises printing conductive ink onto the substrate (1).

3. A method according to claim 1 or claim 2, wherein an opening (40) in a conductive strip (4) is formed by avoiding a corresponding region of the substrate (1) during application of the conductive strip (4).

4. A method according to claim 1 or 2, wherein an opening (40) in a conductive strip (4) is formed by performing a laser ablation step to expose a region of the substrate (1) within the conductive strip (4).

5. A method according claim 1, wherein the openings (40) in a conductive strip (4) are arranged so that the series of openings (40) lies along the sealing path (5) such that a long axis of each opening (40) essentially coincides with the sealing path (5).

6. A method according to claim 1, wherein the number of openings (40) in a conductive line (4) and/or the distance between openings (40) and/or the shape of the openings (40) and/or the size of the openings (40) and/or the orientation of the openings (40) relative to the sealing path (5) are preferably chosen according to known
and/or estimated forces to which the OLED device (10) may be subject during operation.

7. A method according to claim 1, wherein the step of applying a line of sealant (50) comprises applying a line of adhesive (50) onto the conductive strip (4) along the sealing path (5).

8. A method according to claim 7, wherein the step of encapsulating the OLED device (10) comprises a step of applying pressure to the line of sealant (50) to press the adhesive (50) onto the substrate (1) exposed in the openings (40) of a conductive strip (4).

9. A method according to claim 1, wherein the step of applying a line of sealant (51) comprises applying a line of glass solder (51) onto the conductive strip (4) along the sealing path (5).

10. A method according to claim 9, wherein the step of encapsulating the OLED device (10) comprises a laser-assisted glass frit bonding step to melt the glass solder (51) such that the glass solder (51) adheres to the substrate (1) exposed in the openings (40) of a conductive strip (4).

11. An OLED device (10), comprising
   - a number of conductive strips (4) applied onto a substrate (1), wherein at least one conductive strip (4) comprises a series of openings (40) exposing the substrate (1) along a sealing path (50);
   - an organic layer (2) deposited on the substrate (1) within a region bounded by the conductive strips (4);
   - a cover (3) for sealing the OLED device (10);
   - and a line of sealant (50, 51) applied along the sealing path (5), which sealant (50, 51) adheres at least to the cover lid (3) and to the substrate (1) exposed in the openings (40) of the at least one conductive strip (4).
12. An OLED device according to claim 11, wherein a conductive strip (4) has a width in the range of 0.1 mm to 10 mm, and an opening (40) in the conductive strip (4) preferably exposes an area of substrate of at least 0.2 mm².

13. An OLED device according to claim 10 or claim 11, wherein the cover (3) comprises a flat glass lid (3).
A. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both national classification and IPC:

INV. H01L51/52

ADD.

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols): H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched:

Electronic data base consulted during the international search (name of data base and, where practical, search terms used):

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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- **A** document defining the general state of the art which is not considered to be of particular relevance
- **E** earlier document but published on or after the international filing date
- **L** document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another document, or for other special reasons (as specified)
- **O** document referring to an oral disclosure, use, exhibition or other means
- **P** document published prior to the international filing date but later than the priority date claimed

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Name and mailing address of the ISA:
European Patent Office, P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk
Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016

Authorized officer: Persat, Nathalie

See patent family annex.

"P" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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